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An Origin-Centric Communication Scheme to Support Sink Mobility for Continuous Object Detection in IWSNs

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ABSTRACT

In industrial wireless sensor networks, the continuous object detection such as fire or toxic gas detection is one of major applications. A continuous object occurs at a specific point and then diffuses over a wide area. Therefore, many studies have focused on accurately detecting a continuous object and delivering data to a static sink with an energy-efficient way. Recently, some applications such as fire suppression require mobile sinks to provide real-time response. However, the sink mobility support in continuous object detection brings challenging issues. The existing approaches supporting sink mobility are designed for individual object detection, so they establish one-to-one communication between a source and a mobile sink for location update. But these approaches are not appropriate for a continuous object detection since a mobile sink should establish one-to-many communication with all sources. The one-to-many communication increases energy consumption and thus shortens the network lifetime. In this paper, we propose the origin-centric communication scheme to support sink mobility in a continuous object detection. Simulation results verify that the proposed scheme surpasses all the other work in terms of energy consumption.

Keywords : Continuous Objects, Sink Mobility, Energy Efficiency, IWSNs

산업용 무선 센서망을 이용한 연속개체 탐지에서 이동 싱크 지원을 위한 발원점 중심의 통신방안

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요약

오늘날 산업용 무선 센서 망 환경에서 화재나 유독가스와 같은 연속 개체 탐지는 위험성과 대규모 피해로 인해 중요한 문제로 다뤄지고 있다. 연속 개체는 한 지점에서 발생하여 점차 넓은 범위로 확산되는 특징을 가지기 때문에 자원 제약적인 무선 센서 망 환경에서 연속 개체를 탐지한 다수의 센서 노드가 고정 싱크에게 데이터를 전송하게 되면 막대한 통신 오버헤드가 발생하게 된다. 따라서 기존 연구에서는 실시간으로 확장되는 연속 개체를 정확하게 탐지하고, 다량의 센싱 데이터를 에너지 효율적인 방식으로 전송하는 데에 중점을 두었다. 그러나 최근 들어 화재 진압과 같은 실시간 대응이 필요한 응용분야를 위해 연속 개체 탐지에 이동 싱크 도입이 필요하다는 의견이 나타나고 있다. 이러한 경우, 이동 싱크의 위치 갱신을 위해 다수의 소스와 이동 싱크 간 통신이 빈번하게 일어남으로써 무선 센서망의 에너지 소모가 급격하게 증가하는 문제가 발생한다. 본 논문에서는 무선 센서 망을 이용한 연속 개체 탐지에서 이동 싱크를 지원하기 위한 발원점 중심의 통신 방안을 제안한다. 실험결과는 제안 방안이 기존 방안에 비해 이동 싱크의 위치정보 갱신 및 센싱 데이터 보고에 더 적은 에너지를 소모함을 보인다.

키워드 : 연속개체, 모바일 싱크, 에너지 효율, 산업용 무선 센서 망

1. 서 론

In [1], Industrial Wireless Sensor Networks (IWSNs) are wireless sensor networks which have been exerted to industrial environments such as factories, refineries and power plants for measuring, controlling and monitoring applications. Sensor nodes randomly spread over hard-to-

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reach areas to collect data on phenomena of interest in legacy WSN, while they are systematically deployed to detect abnormal conditions in IWSN. Industrial environments have harsh and adverse situations leading to massive casualties and damage, therefore a safety system, for example a fire alarm system, is one of major IWSN applications [2]. Continuous objects such as fire or toxic gas have a marked feature gradually extending over a wide area, thereby activating a multitude of sensor nodes. They usually occur at a point and spread to adjacent areas. Many studies have focused on accurately detecting the contour of a continuous object and reducing communication overhead of data delivery to a static sink. Recently, some applications such as fire suppression require mobile sinks for real-time response in the continuous object detection. As illustrated in the Fig. 1, the fire expands to a wide area over time interval [t0, t4] and a fire fighter with a handheld device can obtain sensing data from a large number of sources.

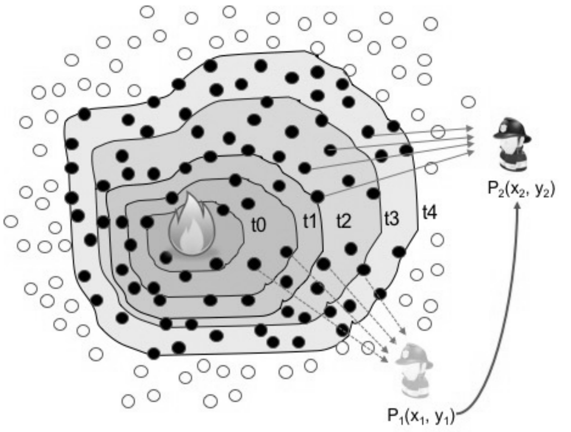


Fig. 1. A Use Case of Continuous Object Detection with a Mobile Sink

However, the sink mobility support in continuous object detection brings challenging issues. A mobile sink, unlike a static sink, should notify sensor nodes of its current location whenever it moves to a new place. If a mobile sink, a fire fighter shown in Fig. 1, moves from P_1 to P_2, it should inform all sources of its updated location to receive sensing data. The current research has developed various approaches to support mobile sinks in individual object detection. They usually exploit a flat-based architecture providing one-to-one communication between a mobile sink and a source for location update. But these approaches are not suitable for continuous object detection since a mobile sink should establish one-to-many communication with a multitude of sources for location update. With the expansion of a continuous object, a mobile sink would have difficulty in locating newly activated sources and communicating with them.

In this paper, we propose the origin-centric communication scheme to support sink mobility (OCS) for continuous object detection. To deal with a large number of sources, it is effective to apply a hierarchy-based architecture rather than a flat-based architecture. A hierarchy-based architecture uses a coordinator delivering location update messages to a multitude of sources on behalf of a mobile sink. Therefore, a mobile sink simply manages one-to-one communication with a coordinator for location update. In OCS scheme, the origin node, the first routing node receiving data from a source, is in charge of the coordinator. The origin node provides the shortest paths to reach all sources since a continuous object diffuses from the origin node. When receiving sensing data from a source, the origin node constructs an origin-centric virtual network to propagate location update messages. The mobile sink notifies the origin node of its current location via the origin-centric virtual network and then the origin node propagates the location update messages on behalf of the mobile sink. The goal of the OCS scheme is to support sink mobility in continuous object detection while reducing network energy consumption. Simulation results verify that our scheme surpasses the other work in terms of energy consumption.

The rest of this paper is organized as follows: Section II introduces the related work including continuous object detection and mobile-sink based routing. Section III presents the OCS scheme in detail and Section IV analyzes communication overhead of the OCS scheme. Simulation results are presented in Section V. Finally, Section VI concludes this paper.

2. Related Work

2.1 Continuous Object Detection Approaches

Energy efficiency is the most serious matter in WSNs since sensor nodes have limited batteries. A continuous object causes a large number of sources resulting in heavy communication overhead between sources and a sink. Many studies on continuous object detection have endeavored to reduce communication overhead by clustering sources or selecting representative nodes. The clustering approaches focus on data aggregation by cluster heads while the selecting approaches aim to reduce the number of sources. In [4], Continuous Object Detection and tracking Algorithm (CODA) provides a static clustering approach for the detection and tracking of continuous objects and Detection and Monitoring for Continuous Object (DEMOCO) [5] exploits selecting representative nodes by communicating among the adjacent boundary nodes. In [6], Soochang Park et al. selects representative nodes from the small candidate set. BRTCO [3] applies a collaborative filtering scheme for boundary nodes. These studies reduce communication overhead on gathering and reporting data in continuous object detection. However, they have focused on energy efficiency of continuous object detection with a static sink, not a mobile sink.

2.2 Mobile-Sink based Routing Approaches

A mobile sink notifies its current location of sensor nodes whenever it moves to a new place. In the case of continuous objects, a mobile sink should notify a multitude of sources of its updated location regularly. The existing studies on sink mobility support have focused on energy- efficient location update for mobile sinks in individual objects detection [7]. Therefore, sink mobility support in continuous object detection brings challenging issues. Haiyun et al. [8] proposed the Two-Tier Data Dissemination (TTDD) where a source builds a source-oriented grid structure in the whole sensor network. A mobile sink can send a data query message to a source and receive sensing data using the source-oriented grid structure. In continuous object detection, TTDD consumes large amounts of energy to build source-oriented grid structures since the number of grid structure increases in direct proportion to that of sources. In [9], the Line-Based Data Dissemination (LBDD) exploits a vertical line called a rendezvous region to separate data reporting from data collecting. A mobile sink sends the closest inline node its location update and then all inline nodes share it. A source also reports data to the closest inline node delivering data to a mobile sink directly. However, LBDD has high data delivery cost since a multitude of data report paths should be established for all sources in continuous object detection. The Grid-Based Energy-Efficient Routing protocol (GBEER) [10] adopts a grid-quorum solution consisting of a request quorum and announcement quorum. A mobile sink sends its cell header a query message and the cell header propagates it through request quorum. A cell header, which is located at the intersection of a request quorum and an announcement quorum, propagates the query message through an announcement quorum. A source receives a query message through an announcement quorum and reports data to the mobile sink directly. Each source establishes a data report path to the mobile sink, thus the GBEER should establish multiple data report paths for all sources in continuous object detection. The Virtual Grid based Dynamic Routes Adjustment (VGDRA) [11] builds a grid structure where each grid cell has a cell-header and constructs an initial route path consisting of cell -headers. A mobile sink sends a location update check message to the closest border-line cell-header [11]. The location update message propagates through the initial route path. Each cell-header collects data from sources and reports it to the mobile sink. However, cell headers assume a heavy responsibility of keeping location updates and delivering data. Ramin et al. [12] uses a grid based virtual infrastructure where intersection nodes keep the current location of mobile sink. When a mobile sink sends its neighbors “my_Pos_MSG” message, they forward the message their intersection nodes, if they are not intersection nodes. When receiving the message, the intersection nodes keep the current mobile sink’s location. Each sensor node knows the closest intersection node and requests the sink position from it. However, [12] has high location update cost since large numbers of sources request mobile sink position of their intersection nodes in continuous object.

According to the study of literature, it is observed that supporting sink mobility in the continuous object detection results in one-to-many communication between a multitude of sources and the mobile sink, thereby causing heavy communication overhead. The major contribution of this paper is to support sink mobility in continuous object detection while saving the entire network’s energy consumption. The OCS scheme offers the mobile sink an efficient way to update its location via the origin-centric virtual network with low energy consumption.

3. Origin-centric Communication Scheme for Sink Mobility Support

3.1 Network Model

Before presenting the OCS scheme, it is important to make sure of several assumptions of the sensor networks. We assume the following characteristics :

- A sensor node is a low energy node with sensing capabilities.
- Sensor nodes are stationary and uniformly distributed across the network.
- Sensor nodes are homogeneous and aware of their locations.
- A routing node is a high energy node with routing capabilities and aware of its location.
- A routing node sends periodic beacon messages to the neighboring routing nodes and updates its neighbor list.
- A routing node is able to communicate in dual mode including low power radio and high power radio.
- A routing node communicates with sensor nodes using low power radio and routing nodes using high power radio.

Sensor nodes are connected the nearby routing nodes using a star topology, whereas routing nodes are connected the other routing nodes using a mesh topology. In this hybrid topology, sensor nodes don't relay any data packets and routing nodes relay and route data packets for other routing nodes and sensor nodes [13]. Thus, the energy consumption of sensor nodes is reduced and the lifetime of sensor network is improved [13, 14]. Fig. 2 shows an example of wireless sensor network.

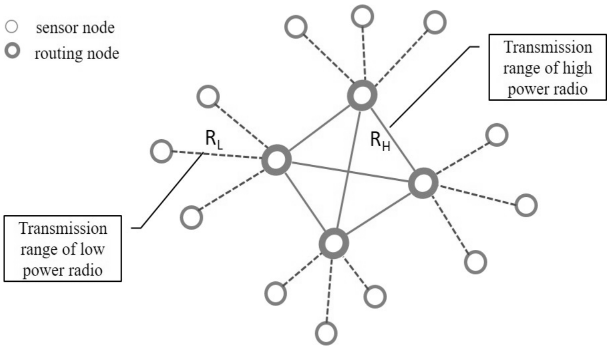
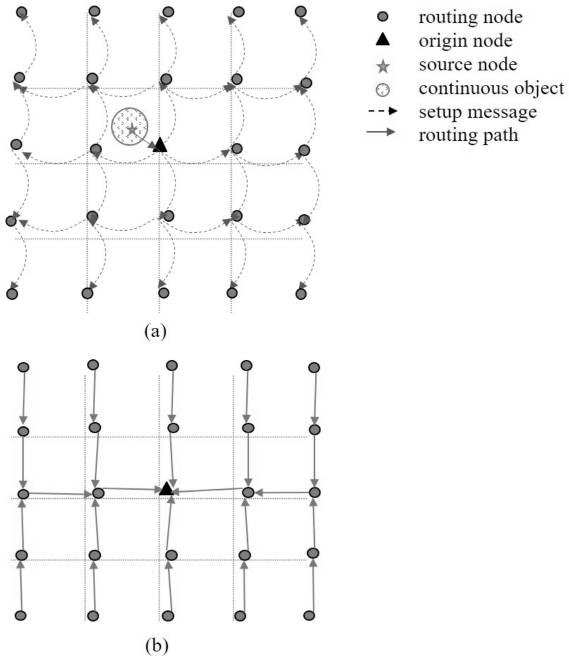


Fig. 2. An Example of Wireless Sensor Network

3.2 Origin-centric Virtual Network Construction

In OCS scheme, the origin node constructs an origin-centric virtual network to propagate location update messages from a mobile sink. When a continuous object occurs at specific location, sources select a source having the highest intensity of sensing. The selected source sends a sensing data to its routing node. The routing node becomes the origin node and then sends setup messages to four neighboring routing nodes to build the origin-centric virtual network. Each routing node notifies the surrounding sensor nodes of its status within its transmission range.

Fig. 3(a) shows the origin node propagates setup messages through routing nodes. When a routing node receives the setup message, it stores data about the message sender and then forwards the message to its four neighboring routing nodes until the message reaches all other routing nodes in the sensor network. After the propagation of setup messages, the initial routing paths between the origin node and all routing nodes are established. Fig. 3(b) illustrates an example of the origin-centric virtual network after initial routes are setup.



(a)

(b)

Fig. 3. Origin-Centric Virtual Network Construction (a) The Propagation of Setup Messages (b) An Example of Origin-Centric Virtual Network After Initial Routes Setup

3.3 Continuous Object Detection

With the expansion of a continuous object, the number of sources increases rapidly leading to heavy communication overhead for reporting data. To reduce communication overhead, we employ a boundary detection and clustering approach where cluster heads aggregate sensing data from boundary nodes and report to a sink.

In Fig. 4, when a sensor node N(x,y) is activated by detecting a continuous object, it asks nearby sensor nodes if they are activated or not. If a sensor node N(x,y) has one or more inactivated neighboring sensor nodes, it becomes a boundary node responsible for reporting data to its routing node. If a boundary node N(x,y) has no inactivated neighboring sensor node, it stops reporting data to its routing node. As shown in Fig. 4, the boundary nodes are replaced by newly activated nodes continuously in accordance with the expansion of the continuous object.

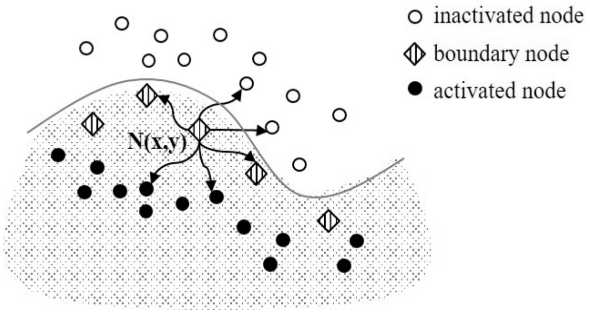


Fig. 4. An Example of Boundary Detection

In OCS scheme, each routing node plays a role as a cluster head for collecting data from boundary nodes and reporting it to the mobile sink. A routing node manages its own state as the continuous object expands dynamically. Fig. 5 shows the state transition diagram of a routing node. A routing node can have three states including initial state, activated Representative Boundary Node (RBN) state and inactivated Representative Boundary Node (RBN) state.

When a routing node receives data from boundary nodes, it changes its state from an initial state to an activated RBN state. The routing node in an activated RBN state reports aggregated data to the mobile sink. If the routing node in an activated RBN state receives no data from boundary nodes, it changes its state from an activated RBN state to an inactivated RBN state. The routing node in an inactivated RBN state stops reporting data to the mobile sink since the boundary of the continuous object already passes its area.

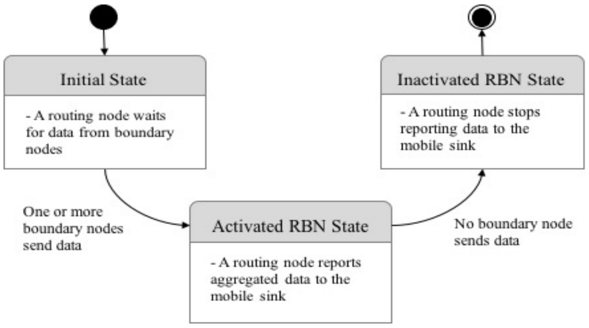


Fig. 5. A State Transition Diagram of a Routing Node

3.4 Two Phase-based Location Update

A mobile sink should periodically notify sources of its current location to collect data. In continuous object detection, the mobile sink should establish one-to-many communication with a multitude of sources. To resolve one-to-many communication problem, the OCS scheme provides the two phase-based location update.

In the first phase, the mobile sink notifies the origin node of its current location whenever it moves to a new place. Fig. 6(a) shows the first phase of location update procedure. The mobile sink sends a location update message to the closest routing node. The routing node sends the message to its upstream routing node in the origin-centric virtual network until the message reaches the origin node.

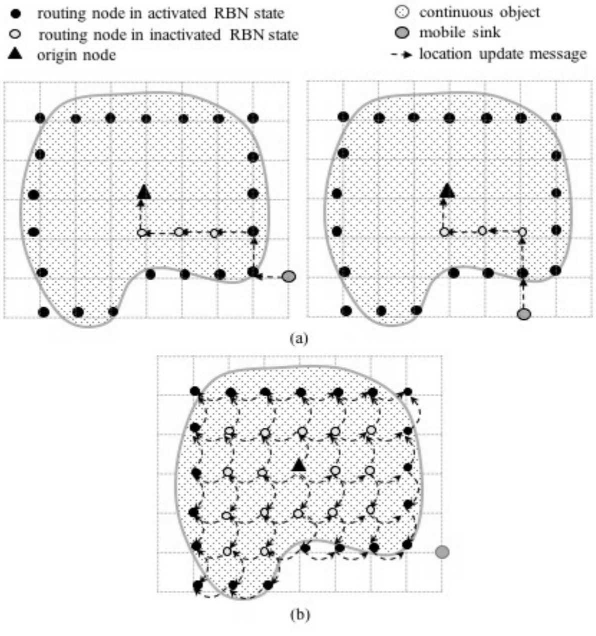


Fig. 6. Two Phase-based Location Update (a) The First Phase of Location Update (b) The Second Phase of Location Update

In the second phase, the origin node propagates the location update message to its four neighboring routing nodes and then each routing node forwards it in the same way until reaching all routing nodes in an activated RBN state. When a routing node in an activated RBN state receives the location update message, it stores mobile sink's location and stops forwarding the message. If a routing node in an activated RBN state receives duplicate messages, it checks the sequence number of the message and drops the message. Fig. 6(b) illustrates the second phase of location update procedure.

On receiving the location update message from the mobile sink, the routing node in an activated RBN state directly reports the aggregated data to the mobile sink using geographic greedy forwarding. The data report path is periodically re-established according to mobile sink's location, thereby providing load balancing among routing nodes and improving the network lifetime.

4. Overhead Analysis

In this section, we analyze the efficiency of the OCS scheme to support a mobile sink in continuous object detection. We estimate the communication overhead in updating the mobile sink's location and reporting data to the mobile sink. We compare the communication overhead of OCS scheme with TTDD[8], GBEER[10], VGDRA[11] and VGB[12]. We assume the other schemes also employ a boundary detection and clustering approach to acquire comparable result. We analyze and compare the total worst-case communication overhead of the OCS scheme and the other mechanisms in this evaluation.

4.1 Model and Notations

We assume a square area A in which N sensor nodes are deployed and each side of it has around $\sqrt{N}$ sensor nodes. Routing nodes are arranged at α-sized intervals where there are around $\sqrt{n}$ sensor nodes between routing nodes. The mobile sink traverses m areas where each area has a routing node at an average speed v in a period time of T. The continuous object gradually spreads within a radius of r in the sensor field. The size of message for location update and announcement is l.

4.2 Communication Overhead

In OCS scheme, the origin node constructs the origin-centric virtual network consisting of routing nodes. The origin node sends four neighboring routing nodes setup messages and then each routing forwards the message to its four neighboring routing nodes. Each routing node notifies the surrounding sensor nodes of its status within its transmission range. The overhead to construct the origin-centric virtual network is:

$$\left\{4\left(\frac{\sqrt{A}}{\alpha}+1\right)^2+\left(\frac{N}{A}\cdot\alpha^2\pi\right)\cdot\left(\frac{\sqrt{A}}{\alpha}+1\right)^2\right\}\cdot l, \tag{1}$$

where $(\sqrt{A}/\alpha+1)^2$ is the number of routing nodes in the sensor network and $(N/A\cdot\alpha^2\pi)\cdot(\sqrt{A}/\alpha+1)^2\cdot l$ is the overhead to notify routing nodes' status to the surrounding sensor nodes.

The mobile sink sends a location update message to the closest routing node and then the routing node forwards the message to the origin node through the origin-centric virtual network. The overhead to deliver a location update message from the mobile sink to the origin node is:

$$\left(\frac{c\sqrt{2}}{2}\cdot\frac{\sqrt{A}}{\alpha}\right)\cdot ml \ \ (0<c\le\sqrt{2}) \tag{2}$$

After receiving a location update message, the origin node propagates it to all routing nodes in an activated RBN state by forwarding the message to four neighboring routing nodes. Given the worst-case communication cost, we assume the continuous object with a diameter of R spreads in the whole sensor field and the overhead to propagate a location update message to all routing nodes in an activated RBN state is:

$$\left\{3\left(\frac{R}{\alpha}+1\right)^2\right\}\cdot ml, \tag{3}$$

where $(R/\alpha+1)^2$ is the number of routing nodes in the path from the origin node to the routing nodes in an activated RBN state.

On receiving the location update message, routing nodes in an activated RBN state sends the aggregated data to the mobile sink using geographic greedy forwarding and the overhead to deliver data to the mobile sink is:

$$\left\{\left(2\pi r\cdot\frac{\sqrt{N}}{\sqrt{A}}\right)+\left(\frac{2\pi r}{\alpha}\cdot\frac{c\sqrt{A}}{\alpha}\right)\right\}\cdot ml\ , \tag{4}$$

$(0<c\le\sqrt{2})$

where $(2\pi r \cdot \sqrt{N}/\sqrt{A}) \cdot ml$ is overhead to collect data from boundary nodes and $(2\pi r/\alpha \cdot c\sqrt{A}/\alpha) \cdot ml$ is the overhead to report data to the mobile sink.

The total worst-case communication overhead of the OCS scheme is:

$$\begin{aligned}
&\left\{4\left(\frac{\sqrt{A}}{\alpha}+1\right)^2+\left(\frac{N}{A}\cdot\alpha^2\pi\right)\cdot\left(\frac{\sqrt{A}}{\alpha}+1\right)^2\right\}\cdot l \\
&+\left\{\left(\frac{c\sqrt{2}}{2}\cdot\frac{\sqrt{A}}{\alpha}\right)+3\left(\frac{R}{\alpha}+1\right)^2\right\}\cdot ml \\
&+\left\{\left(2\pi r\cdot\frac{\sqrt{N}}{\sqrt{A}}\right)+\left(\frac{2\pi r}{\alpha}\cdot\frac{c\sqrt{A}}{\alpha}\right)\right\}\cdot ml \\
&\left(0<c\le\sqrt{2}\right)
\end{aligned} \tag{5}$$

In TTDD [8], the mobile sink sends the immediate dissemination node a location update message by locally flooding a data query message with its location information and then the message is forwarded to activated boundary nodes through their source-oriented grid structures. The total worst-case communication overhead of the TTDD is:

$$\begin{aligned}
&\left\{2\left(\sqrt{N}\cdot\frac{\sqrt{A}}{\alpha}\right)\cdot\left(\frac{2\pi r}{\alpha}\cdot\frac{\sqrt{N}}{\sqrt{A}}\right)\right\}\cdot l \qquad , \\
&+\left\{n+\frac{\sqrt{2}\,(c\sqrt{N})}{2}\cdot\frac{\sqrt{N}}{\sqrt{A}}\cdot 2\pi r\right\}\cdot ml \\
&+\left\{\left(\frac{2\pi r}{\alpha}\cdot\sqrt{2N}\right)+\left(2\pi r\cdot\frac{\sqrt{N}}{\sqrt{A}}\right)\cdot\frac{\sqrt{2n}}{2}\right\}\cdot ml \\
&\left(0<c\le\sqrt{2}\right)
\end{aligned} \tag{6}$$

where $\{2(\sqrt{N}\cdot\sqrt{A}/\alpha)\cdot(2\pi r/\alpha\cdot\sqrt{N}/\sqrt{A})\}\cdot l$ is the overhead to construct source-oriented grid structures as many as cluster heads and the overhead to deliver location update messages to cluster heads is $(n+c\sqrt{2N}/2\cdot\sqrt{N}/\sqrt{A}\cdot 2\pi r)\cdot ml$. The overhead to report data to the mobile sink is $(2\pi r/\alpha\cdot\sqrt{2N})\cdot ml$ $+\{(2\pi r\cdot\sqrt{N}/\sqrt{A})\cdot\sqrt{2n}/2\}\cdot ml$.

In GBEER [10], the mobile sink sends a data request packet with its location information to the immediate node forwarding it to the immediate header using the greedy geographic forwarding. The immediate header disseminates the data request packet to cell headers in the request quorum. A source sends data announcement packet to its cell header propagating it through the announcement quorum [10]. A cell header receiving both data request packet and data announcement packet forwards the data request packet to source's header. The total worst-case communication overhead of the GBEER is:

$$\begin{aligned}
&2\left(\sqrt{N}\cdot\frac{\sqrt{A}}{\alpha}\right)\cdot l+(\sqrt{2n}\cdot N)\cdot l \qquad , \\
&+\left\{\left(2\pi r\cdot\frac{\sqrt{N}}{\sqrt{A}}\right)\cdot\sqrt{2n}+\sqrt{N}\cdot\frac{2\pi r}{\alpha}+\sqrt{2n}\right\}\cdot l \\
&+\left(n+1+2\sqrt{2n}+\sqrt{N}\right)\cdot ml \\
&+\left\{\left(\frac{2\pi r}{\alpha}\cdot\sqrt{2N}\right)+\left(2\pi r\cdot\frac{\sqrt{N}}{\sqrt{A}}\right)\cdot\frac{\sqrt{2n}}{2}\right\}\cdot ml
\end{aligned} \tag{7}$$

where $\{2(\sqrt{N}\cdot\sqrt{A}/\alpha)+(\sqrt{2n}\cdot N)\}\cdot l$ is the overhead to construct a grid structure including selecting cell headers. In Equation 7, $\{(2\pi r\cdot\sqrt{N}/\sqrt{A})\cdot\sqrt{2n}$ $+\sqrt{N}\cdot 2\pi r/\alpha+\sqrt{2n}\}\cdot l$ is the overhead to announce sensing data in the announcement quorum and $(n+1+2\sqrt{2n}+\sqrt{N})\cdot ml$ is the overhead to request data of sources. The overhead to report data to the mobile sink is $\{(2\pi r/\alpha\cdot\sqrt{2N})+(2\pi r\cdot\sqrt{N}/\sqrt{A})\cdot\sqrt{2n}/2\}\cdot ml$.

In VGDRA [11], it construct a virtual backbone structure consisting of cell headers and set up initial communication routes considering the mobile sink's location. The mobile sink receives data from the originating cell-header, the closest border-line cell-header to the mobile sink. The originating cell-header shares the mobile sink's location with the rest of the cell-headers to maintain the latest routes. The total worst-case communication overhead of the VGDRA is:

$$\begin{aligned}
&2\left(\sqrt{N}\cdot\frac{\sqrt{A}}{\alpha}\right)\cdot l+\left(\frac{\sqrt{n}}{2}\cdot N\right)\cdot l \qquad , \\
&+\left\{\left(\frac{N}{A}\cdot\pi\cdot\left(\frac{\sqrt{2}\,\alpha}{2}\right)^2\right)\cdot\sqrt{2n}\cdot\frac{A}{\alpha^2}\right\}\cdot l \\
&+\left(4\sqrt{n}\cdot\frac{A}{\alpha^2}\right)\cdot l+(\sqrt{N}+2\sqrt{n})\cdot ml \\
&+\left(\frac{2\pi r}{\alpha}\cdot 2\sqrt{N}\right)\cdot ml \\
&+\left(2\pi r\cdot\frac{\sqrt{N}}{\sqrt{A}}\right)\cdot\frac{\sqrt{2n}}{2}\cdot ml
\end{aligned} \tag{8}$$

where $\{2(\sqrt{N}\cdot\sqrt{A}/\alpha)+(\sqrt{n}/2\cdot N)\}\cdot l$ is the overhead to construct a grid structure including selecting cell-headers. In Equation 8, the overhead to announce cell-headers is $\{(N/A\cdot\pi(\sqrt{2}\,\alpha/2)^2)\cdot\sqrt{2n}\cdot A/\alpha^2\}\cdot l$ and the overhead to share information about the second cell-header is $(4\sqrt{n}\cdot A/\alpha^2)\cdot l$. The overhead to deliver a location update message is $(\sqrt{N}+2\sqrt{n})\cdot ml$ and the overhead to report data to the mobile sink is $\{(2\pi r/\alpha\cdot 2\sqrt{N})+(2\pi r\cdot\sqrt{N}/\sqrt{A})\cdot(\sqrt{2}\,\alpha/2)\cdot\sqrt{N}//\sqrt{A})\}\cdot ml$.

In VGB [12], it builds a virtual grid structure consisting of same-sized cells. After constructing the virtual grid structure, it selects several sensor nodes as intersection nodes [12]. The mobile sink sends its neighbors "my_Pos_MSG" message which is forwarded to their intersection nodes. A source sends a request sink position message to the corresponding intersection node and reports data to the mobile sink by the geographic routing algorithm. The total worst-case communication overhead of the VGB is:

$$\begin{aligned}&2\left(\sqrt{N}\cdot\frac{\sqrt{A}}{\alpha}\right)\cdot l\\&+\left\{\left(\frac{\sqrt{A}}{\alpha}-1\right)^2\cdot\left(\frac{N}{A}\cdot\pi\alpha^2\right)\cdot\frac{\sqrt{n}}{2}+N\cdot\sqrt{2n}\right\}\cdot l\\&+\left\{\sqrt{2n}+4\sqrt{n}\cdot\left(\frac{\sqrt{A}}{\alpha}-1\right)^2\right\}\cdot ml\\&+\left\{2\left(\frac{2\pi r}{\alpha}\cdot\sqrt{2n}\right)+\frac{2\pi r}{\alpha}\cdot\sqrt{2N}\right\}\cdot ml\\&+\left(2\pi r\cdot\frac{\sqrt{N}}{\sqrt{A}}\right)\cdot\frac{\sqrt{2n}}{2}\cdot ml\end{aligned}\quad, \tag{9}$$

where $2(\sqrt{N}\cdot\sqrt{A}/\alpha)\cdot l$ is the overhead to construct a virtual grid structure and $\{(\sqrt{A}/\alpha-1)^2\cdot(N/A\cdot\pi\alpha^2)\cdot\sqrt{n}/2\}\cdot l$ is the overhead to select intersection nodes. In Equation 9, the overhead to announce intersection nodes is $N\cdot\sqrt{2n}\cdot l$ and the overhead to deliver my_Pos_MSG message to intersection nodes is $\{\sqrt{2n}+4\sqrt{n}\cdot(\sqrt{A}/\alpha-1)^2\}\cdot ml$. The overhead to report data to the mobile sink is $\{2(2\pi r/\alpha\cdot\sqrt{2n})+2\pi r/\alpha\cdot\sqrt{2N}+(2\pi r\cdot\sqrt{N}/\sqrt{A})(\sqrt{2}\alpha/2\cdot\sqrt{N}/\sqrt{A})\}\cdot ml$.

For example, there is a sensor network consisting of N = 1000 sensor nodes in a square area A = 600m×600m, routing nodes are arranged at α-sized intervals where α is 60m. Suppose a radius of a continuous object r = 200m, c = 1 and l = 1. the mobile sink traverses m = 10 areas. With applying those values to equations we have some comparison results such as $CO_{OCS}/CO_{TTDD}\approx 0.007$, $CO_{OCS}/CO_{GBEER}\approx 0.004$, $CO_{OCS}/CO_{VGDRA}\approx 0.01$, $CO_{OCS}/CO_{VGB}\approx 0.01$. In this network model, the OCS scheme has significantly lower communication overhead than other mechanisms.

5. Performance Evaluation

In this section, we evaluate the performance of OCS with TTDD[8], GBEER[10], VGDRA[11] and VGB[12]. We implement the four schemes in NS-2 simulator. In the simulation environment, the 1000 sensor nodes are uniformly deployed in a 600m×600m sensor field. A sensor node consumes 21mW and 15mW for transmitting and receiving respectively [15]. Routing nodes are arranged at α-sized intervals where α is 60m. The 20m×20m continuous object is occurred at the center of sensor field, (300, 300). We consider the radius of a continuous object increases by 20m in each time slot until 200m. The Random Waypoint (RWP) [16] mobility model is used for the mobile sink. The mobile sink moves along the edge of the sensor field at an average speed of 2m/s and sends a location update message every 5sec.

We assume that TTDD, GBEER, VGDRA and VGB also employ a boundary detection and clustering approach where cluster heads report data to the mobile sink, since the OCS scheme exploits routing nodes to collect from boundary nodes and report it to the mobile sink. We analyze the performance results compared to the revised four schemes. We select two metrics to evaluate the performance of the OCS scheme : the location update cost, the data delivery cost.

5.1 The Location Update Cost

The location update cost estimates the nodes' energy consumption in constructing a virtual structure and updating mobile sink's location. Fig. 7 compares the nodes' energy consumption of the OCS scheme with the other schemes when the network size increases.

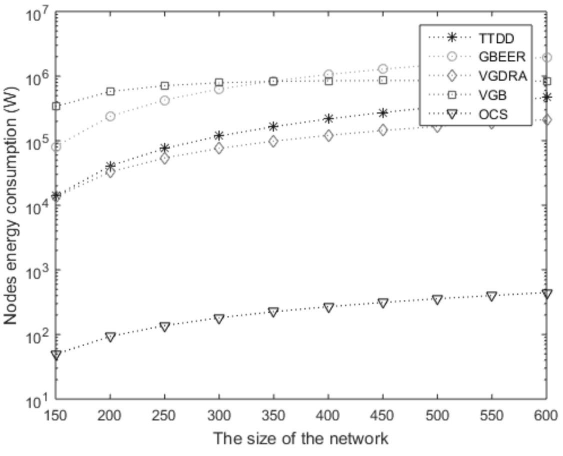


Fig. 7. Comparing Nodes Energy Consumption in Updating Mobile Sink's Location for Different Sizes of Network

The TTDD consumes considerable energy to construct source-oriented grid structures as many as the number of cluster heads having boundary nodes. Therefore, the mobile sink sends data query messages to all cluster heads via their source-oriented grid structures. The overhead for delivering data query messages exponentially grows as the sensor network size increases. The GBEER exploits the concept of a grid-quorum solution for location update. The mobile sink sends data request packets to cell headers having boundary nodes and then data request packets are propagated through data request quorum and data announcement quorum. As the sensor network size increases, the number of sensor nodes in data request paths also increases, thereby causing high communication overhead. The VGDRA builds the virtual backbone network by dividing the network and establishing adjacencies per a cell-header. After constructing the virtual backbone network, it setups initial communication routes consisting of all cell-headers and re-establishes communication routes considering mobile sink's location. The communication overhead to setup communication routes increases according to the size of the sensor network. The VGB constructs a grid-based virtual infrastructure by partitioning the network and selecting intersection nodes. The mobile sink sends its neighbors location update messages which are forwarded to all intersection nodes. As the sensor network size increases, the number of intersection nodes proportionally increases, thereby causing heavy communication overhead. The OCS scheme exploits the origin-centric virtual network consisting of routing nodes. The mobile sink sends the origin node a location update message through the origin-centric virtual network and then the origin node forwards the message to routing nodes in an activated RBN state. Therefore, the overhead for location update has a relationship with the number of routing nodes. As the sensor network size increases, the number of routing nodes is relatively smaller than that of sensor nodes, thereby causing low communication overhead. As illustrated in Fig. 7, the OCS scheme consumes least amount of energy compared to other schemes.

Fig. 8 shows the comparison of location update cost with varying the radius of the continuous object. The expansion of a continuous object causes an increase in the number of cluster heads having boundary nodes, thereby resulting in heavy communication overhead for location update. In TTDD, the mobile sink sends data query messages to cluster heads having boundary nodes through their source-oriented grid structures. The number of cluster heads having boundary nodes increases in direct proportion to the size of a continuous object leading to heavy communication overhead. In GBEER, the mobile sink sends its neighbors data request packets which are forwarded to cell headers having boundary nodes using greedy geographic forwarding. Thus, the expansion of the continuous object causes the number of cell headers having boundary nodes, thereby resulting in high communication overhead. The VGDRA setups the initial communication route in the sensor network and then adjusts the initial communication route locally whenever the mobile sink sends a location update message. Thus, the VGDRA has high communication overhead setting up the initial communication routes irrespective of the continuous object size. In VGB, the mobile sink sends its neighbors location update messages which are forwarded to all intersection nodes. Therefore, in VGB, high communication overhead is related to the number of intersection nodes irrespective of the continuous object size. The OCS scheme propagates a location update message to all routing nodes in an activated RBN state through the origin-centric virtual network. Thus, the communication overhead for location update increases in proportion to the number of routing nodes in an activated RBN state. As shown in Fig. 8, using the OCS scheme, the nodes' energy consumption is less compared to the other schemes.

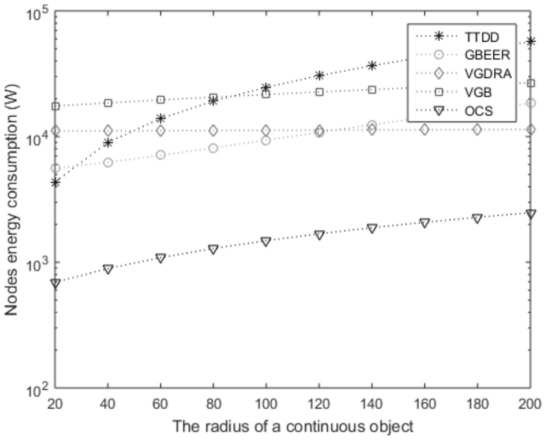


Fig. 8. Comparing Nodes Energy Consumption in Updating Mobile Sink's Location for Different Sizes of a Continuous Object

5.2 The Data Delivery Cost

The data delivery cost estimates the nodes' energy consumption in aggregating sensing data from boundary nodes and delivering the aggregated data to the mobile sink.

In TTDD, cluster heads having boundary nodes aggregate data and report it to the mobile sink using their source-oriented grid structures. The communication overhead increases in proportion to the number of sensor nodes in

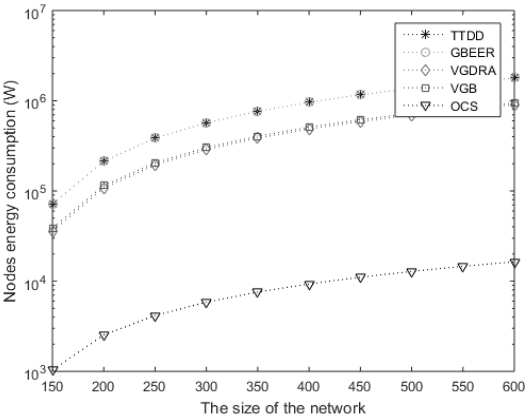


Fig. 9. Comparing Nodes Energy Consumption in Reporting Data to the Mobile Sink for Different Network Sizes

the data delivery path, which means it increases according to the sensor network size. In GBEER, cluster heads having boundary nodes directly send data to the mobile sink using greedy geographic forwarding. Thus, the communication overhead increases in proportion to the number of sensor nodes between cluster heads and the mobile sink. In VGDRA, cell-headers having boundary nodes aggregate and report data to the mobile sink via the virtual network. As the sensor network size increases, the number of sensor nodes and cell-headers also increases, thereby resulting in high communication overhead. In VGB, cluster heads having boundary nodes send request sink position messages to the corresponding intersection nodes and then cluster heads report the aggregated data to the mobile sink using the geographic routing algorithm. The communication overhead is related to the number of sensor nodes between cluster heads and the mobile sink. Therefore, the communication overhead increases depending on the sensor network size. In OCS scheme, routing nodes in an activated RBN state directly report data to the mobile sink using geographic greedy forwarding. Therefore, the data delivery cost depends on the number of routing nodes between routing nodes in an activated RBN state and the mobile sink. As shown in Fig. 9, using the OCS scheme, the nodes energy consumption in delivering the aggregated data to the mobile sink is considerably less compared to the other schemes.

6. Conclusion

In this paper, we propose the origin-centric communication scheme to support sink mobility for continuous object detection. The existing studies to support sink mobility exploit a flat-based architecture establishing one-to-one communication between a mobile sink and a source. However, these studies are not suitable for continuous object detection leading to one-to-many communication problem with numerous sources. The OCS scheme employs a hierarchy-based architecture to solve one-to-many communication problem. Therefore, the mobile sink simply manages one-to-one communication with the origin node using the origin-centric virtual network for location update and then the origin node forwards location update messages to routing nodes in an activated RBN state. The simulation results showed the OCS scheme outperforms the other work in reducing the location update cost and data delivery cost.

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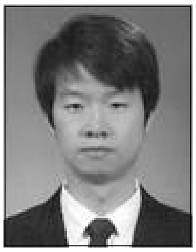

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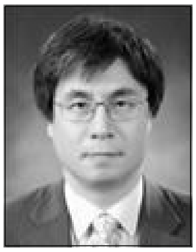

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